Magnetic Field Cloaking Device

eRD2 Progress Report

Raphael Cervantes, Abhay Deshpande, Nils Feege

SUNY Stony Brook

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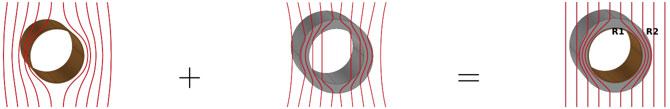
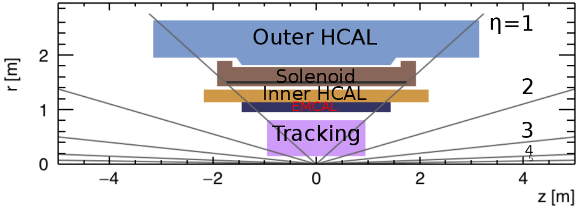
Conceptual Magnetic Cloak



(a) Superconductor (b) Ferromagnet (c) Magnetic Cloak

$$\mu_r = \frac{R_2^2 + R_1^2}{R_2^2 - R_1^2}$$

Goal: To improve momentum resolution in the high η region.



Place dipole + magnetic cloak in high η region.

Key Points

Proof of concept demonstrated at SBU.

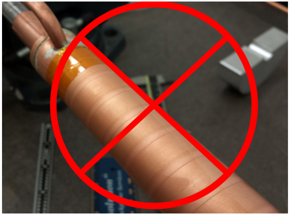
- Demonstrated shielding for 55 mT.
- Established methodology to predict shielding performance to arbitrary n layers. Can determine requirements to shield 0.5 T.
- Established procedure to fabricate ferromagnet with proper permeability/thickness for cloaking.
- Achieved cloaking with new materials.

Progress beyond this point needs:

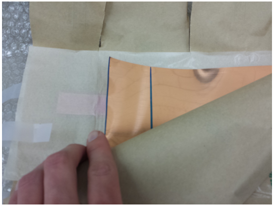
- Superconducting Magnet Division (SMD) expertise/infrastructure to test prototypes at higher fields, in liquid He.
- Collider-Accelerator Department (CAD) expertise to design cloak for accelerator applications.

Exploring Superconductor Options

6 months ago we tried commercial tape.
Didn't work!
5 layers shields $\simeq$ 10 mT.



Alternatives to 12 mm wide tape:

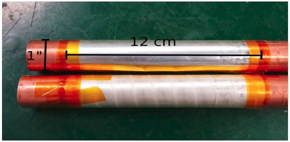


NbTi
$T_c = 10$ K

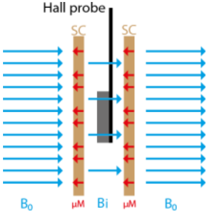
MgB_2
$T_c = 40$ K

Wider Tape
$T_c = 93$ K

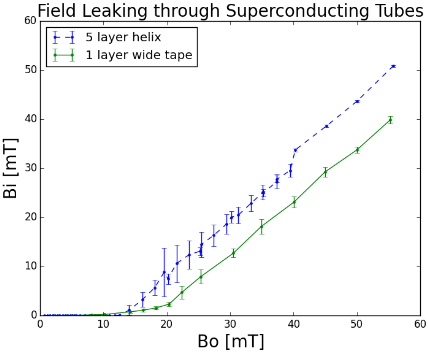
Shielding with HTS: 12 mm vs 46 mm Tape



46 mm wide tape wrapped longitudinally vs 12 mm wide tape wrapped helically

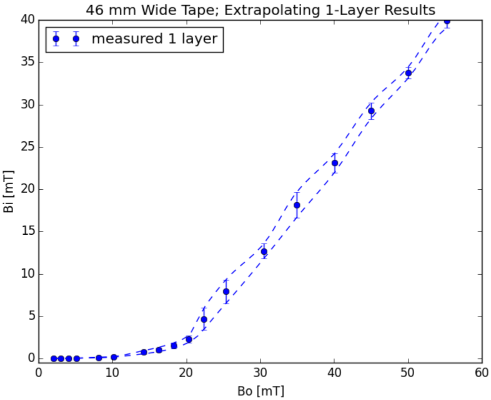


SC shielding measurement.

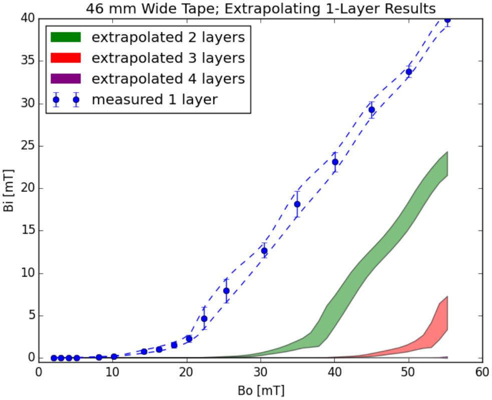


Wide tape huge improvement over 12 mm helix winding for shielding transverse fields

Adding Multiple Layers to Improve Performance

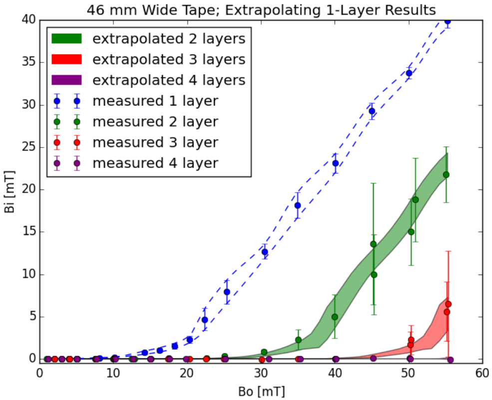


Adding Multiple Layers to Improve Performance



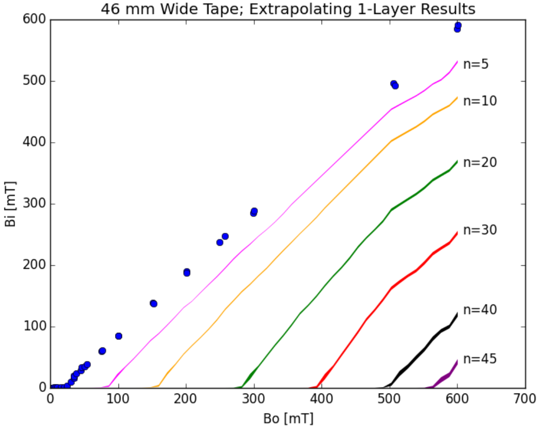
From 1-layer measurement, predict shielding of N layers.

Adding Multiple Layers to Improve Performance



Shielding of N layers predicted from 1-layer measurement.
Measurement agrees with prediction!
Shield > 50 mT with HTS tape at $T = 77$ K. Unprecedented in literature.

Scaling Performance to 0.5 T

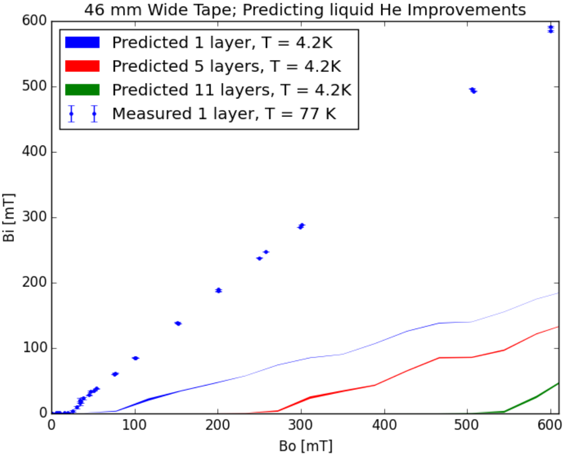


Superconducting tape in dipole field.

Can shield 0.5 T with 40 layers.

Predicting Performance in liquid He

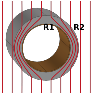
$$B_i(B_o, T = 4.2K) = B_i(\frac{B_c(T=77K)}{B_c(T=4.2K)} \times B_o, T = 77K).$$



Can shield 0.5 T with 11 layers.

Ferromagnet Production

Cloaking Condition: $\mu_r = \frac{R_2^2+R_1^2}{R_2^2-R_1^2}$



(a) 430 Stainless Steel Powder, $\mu_r \simeq 500$

$+$

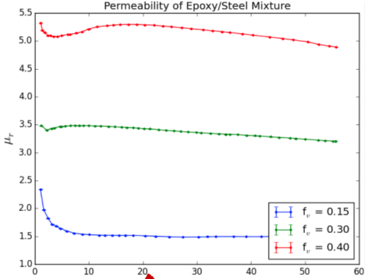
(b) Epoxy, $\mu_r = 1$

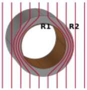
$=$

(c) FM Epoxy, $1 < \mu_r < 6$

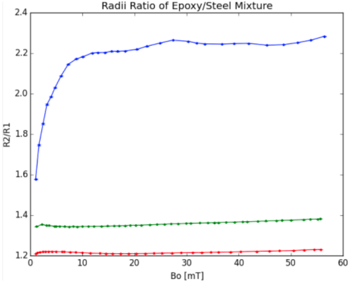
Mix steel powder in epoxy. Pour epoxy into mold.
Adjust fractional volume of steel powder between $f_v = 0$ and $f_v = 0.4$ to adjust permeability.

Adjusting Permeability of Ferromagnet





$$\frac{R2}{R1} = \sqrt{\frac{\mu_r+1}{\mu_r-1}}$$

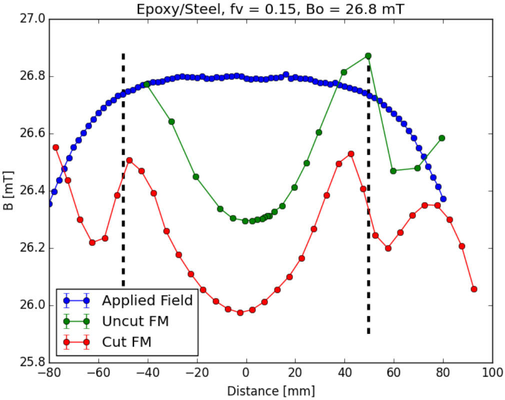


$$\mu_r = \frac{R_2^2+R_1^2}{R_2^2-R_1^2}$$

Need to characterize to 0.5 T.

Ferromagnet is Homogeneous, can be "Stitched" Together

(a)

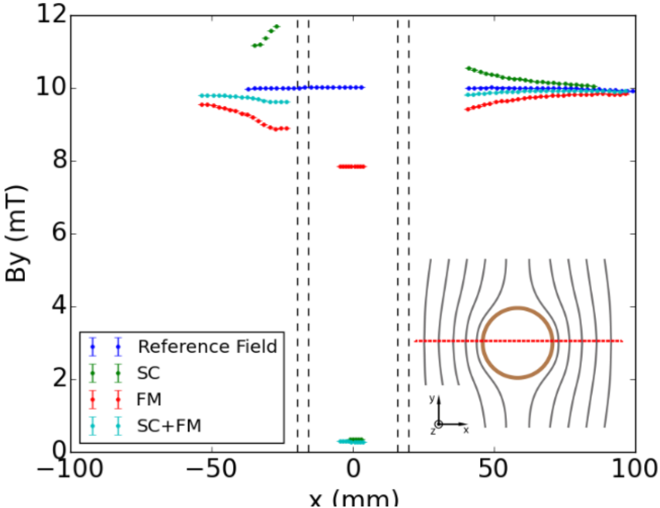


(b)

No kink in center!

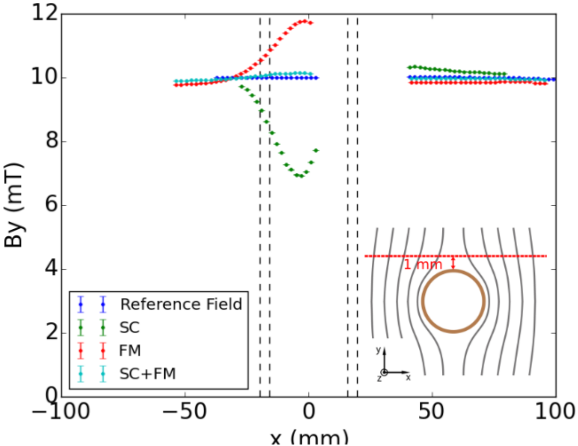
Difference likely due to hysteresis?

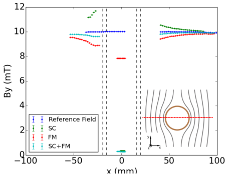
Cloaking Achieved



Cloak field close to reference field.

Cloaking Achieved





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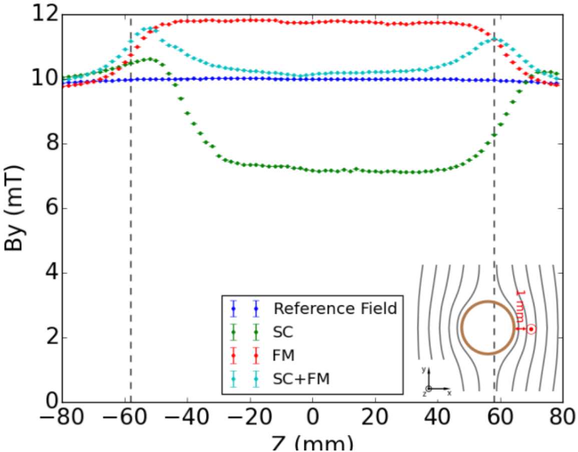

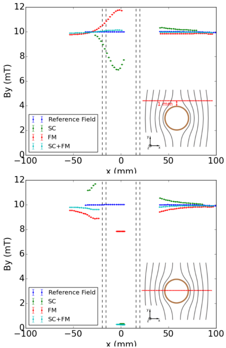

Can remove edge effects by making cloak longer than field.

Cloak Material Budget

SC Options to shield 0.5 T transverse field:

	Cooling	Layers	Thickness [mm]	X0 (orthogonal crossing)
NbTi/Nb/Cu	lHe	1	1	0.067 X0
AMSC SC 46 mm	lHe	11	0.9	0.086 X0
AMSC SC 46 mm	lN2	45	3.6	0.352 X0

Ferromagnet Layer Option (50 mT reference)

	VolFrac	Layers	Thickness [mm]	X0 (orthogonal crossing)
Epoxy / Steel	0.4	1	3.7	0.033 X0

Next Steps and Open Questions

Will get done by next progress report
Need help for SMD/CAD to proceed
Somewhere in between

1. *Demonstrate cloaking at 0.5 T.*
2. *What is the radiation hardness of ferromagnetic and superconducting material?*
3. *Could thermal effects due to accidental beam dumps damage the structure?*
4. *What is the physics benefit for a conceptual forward dipole spectrometer?*
5. *What is the effect of possible cryostat and its flanges on the detector acceptance and performance at small angles?*
6. *Summarize results in a publication.*

Budget Requests

Item	**Cost [$]**
2 Salaries and Benefits	
Post-doc (100% for 3 months)	12,500
+ Benefits	5,438
Graduate Student (100% for 12 months)	25,000
+ Benefits	3,500
+ Tuition	4,188
3 Undergraduate students (8 weeks during summer)	4,800
+ Benefits	240
Travel	
Domestic, Conferences	3,000
Supplies and Equipment	
Liquid Helium, Liquid Nitrogen	5,000
Superconductor Materials	9,000
1 Other	
BNL SMD (expert advice, magnets, infrastructure)	10,000
Total Direct Cost	82,700
Total Indirect Cost (Overhead)	40,300
Total Request	**123,000**

Summary

1. Achieved shielding at 50 mT.
2. Established methodology to predict shielding performance of multilayer superconductor.
3. Demonstrated ability to fine tune ferromagnet layer to achieve cloaking.
4. Demonstrated cloaking with new materials.
5. Need to coordinate with SMD to proceed.

Thank You!

Additional Slides

46 mm wide SC is Ferromagnetic

AMSC 2G Technology

Based on low-cost RABITS^{TM}/MOD Architecture

amsc

- **Substrate: Ni-5W alloy**
  - Deformation texturing
- **Buffer stack: Y_2O_3/YSZ/CeO_2**
  - High rate reactive sputtering
- **YBCO, the HTS part**
  - Metal Organic Deposition of TFA-based precursors
- **Ag**
  - DC sputtering